

The application of augmented reality in competency-based learning

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ABSTRACT

This research aims to overcome several challenges in vocational education, primarily related to the lack of learning tools and the development of 21st-century skills such as critical thinking, communication, collaboration, and creativity. This research uses the research and development (R&D) model with the ADDIE development procedure, with the steps analysis, design, development, implementation, and evaluation. Data was collected through surveys, interviews, and observations of students and teachers during the teaching and learning process. The research results show that the augmented reality-competency based learning (AR-CBL) application effectively increases students' understanding of computer network material. Apart from that, AR-CBL also has the potential to be an interactive learning tool that can improve student learning motivation. The AR-CBL learning model resulting from this research can support the development of technical skills and critical thinking, communication, collaboration, and creativity (4C) abilities. The implementation of AR-CBL also has the potential to improve educational standards in vocational schools and help graduates better match industry needs. With the results of this research, schools and education stakeholders can consider using AR-CBL technology in the vocational school curriculum to prepare graduates to face the world of work in this digital era.

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1. INTRODUCTION

In the context of vocational education, digital technology is becoming increasingly important in providing students with knowledge and skills relevant to the demands of the modern world of work [1], [2]. With rapid information and communication technology (ICT) developments, ICT-based learning has enabled the concept of "learning anytime, anywhere," which expands access and flexibility in the learning process [3]–[5]. With nearly all individuals having access to mobile devices and online resources, students have an excellent opportunity to deepen their understanding of technical skills. However, digital learning also brings challenges, especially regarding time management and distractions [3], [4]. Students must understand how to manage their time and avoid unnecessary digital distractions to get the most out of online learning [5], [6]. In this case, educators must provide students with the necessary guidance and support.

Innovations in learning, such as augmented reality (AR), provide exciting new opportunities. AR allows students to combine the real world with virtual elements, creating a more interactive and immersive learning experience [7], [8], it helps students explore complex concepts more engagingly, promoting better

understanding. The use of technology in vocational education is a must, especially in the current digital era. Students must be equipped with relevant technology skills to compete in an increasingly connected world of work [9], [10]. However, to ensure the success of digital learning, educators need to provide guidance, support, and a supportive environment so that students can optimize the benefits of this technology. Innovations like AR also add a new dimension to learning, making learning more exciting and compelling.

Innovative educational approaches leverage AR technology to create immersive learning experiences that transcend traditional boundaries [11]. By seamlessly integrating virtual elements into real-world environments, AR enriches the educational journey by fostering active engagement and deepening understanding [12]. This innovative approach enhances user interaction and cultivates a sense of presence and immersion, making learning more impactful and memorable [13], [14]. As AR continues to evolve, its integration into online learning platforms represents a cutting-edge advancement in educational innovation, offering boundless opportunities for personalized, experiential learning across diverse fields and disciplines.

The integration of AR in educational settings has been shown to enhance student learning outcomes. A recent systematic review and meta-analysis by Zhang *et al.* [15] demonstrated that the use of augmented reality in higher education produces a large positive effect on learning outcomes, confirming its potential to significantly improve students' academic performance across diverse disciplines. Numerous meta-analysis by various researchers have demonstrated the effectiveness of AR-assisted instruction in boosting learning [16], [17]. Bacca *et al.* [18] recent study further underscores the ongoing trend of incorporating AR into education, covering advancements in AR technology, current research trends, and its applications within educational contexts [19]–[20]. However, its deployment also encounters several technical and infrastructural hurdles that must be addressed. The latest trends indicate that the relevance of AR as an instructional tool continues to grow in education.

AR technology has emerged as a compelling area of study in vocational education, though it comes with its own set of challenges and issues that need resolution [21]. Despite the growing popularity of this technology, not all students or educational institutions possess the necessary resources or tools to leverage it effectively [22], [23]. Another crucial factor is instructional design in AR implementation. For AR to reach its full potential in learning environments, educational materials must be well-crafted and aligned with learning objectives [24]. In terms of teacher competency in ICT, educators need suitable training to integrate AR technology into their teaching methodologies effectively [25], [26]. Therefore, investigating these issues through further research will aid in expanding the utilization of AR as a practical learning tool.

There is a need to develop an AR application explicitly tailored to aid computer network learning. This application should enable students to construct virtually and engage with computer network models. The competency-based learning (CBL) model highlights the importance of students acquiring specific skills. Consequently, this AR application should facilitate the development of critical thinking, communication, collaboration, and creativity (4C) competencies. This approach is anticipated to make the learning process more interactive and engaging for students while providing practical opportunities to apply their theoretical knowledge and cultivate essential 21st-century skills.

2. METHOD

2.1. Methodological framework

This study adopts a constructivist epistemological stance within its research philosophy. This choice is rooted in the understanding that individuals construct meaning and knowledge socially [27]. Within the constructivist paradigm, this research is positioned because it directly addresses the study's research questions. These inquiries investigate the efficacy of augmented reality-competency based learning (AR-CBL) application in facilitating learning computer networks within vocational high schools. Hence, this condition relates to the constructivist paradigm since it asserts that meaning and realities are constructed by people who experience the world based on their viewpoints. Therefore, data was collected through surveys, interviews, and observations of students and teachers during the teaching and learning process.

This study utilized the research and development (R&D) or educational design research approach, a framework created to develop and improve existing products [28]. This concept is seen as a process that applies research and product development to meet needs in educational institutions [29]. Educational design research aims to provide solutions in solving problems in the education sector, building and testing theories around learning processes and learning environments [30]. The ADDIE model, consisting of the stages of analysis, design, development, implementation, and evaluation, is the reference in this study. Based on the ADDIE instructional design procedures in Figure 1, several concepts and procedures must be carried out. It can be seen that the ADDIE model regulates them clearly, specifically, and systematically so that they can be quickly followed.

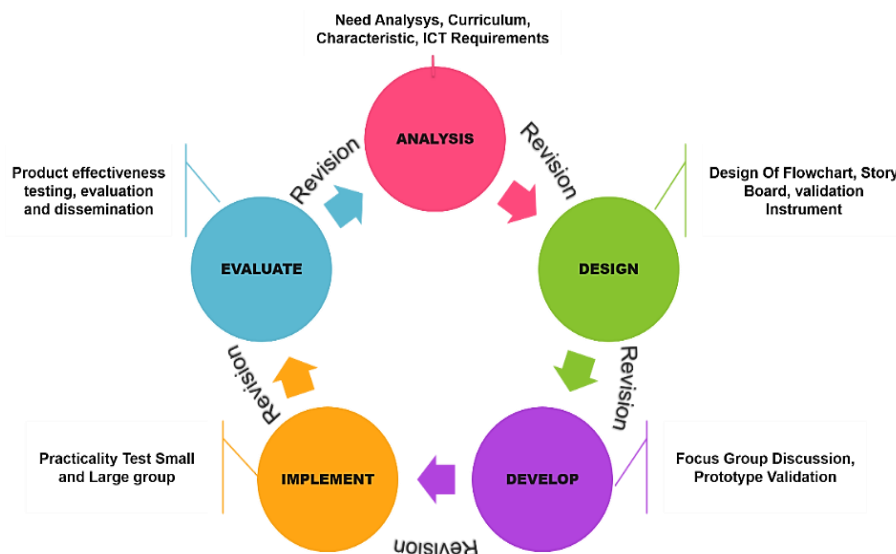


Figure 1. ADDIE development model diagram

2.2. Research instrument

The researchers in this study employed a variety of research instruments to collect and measure data. Researchers conducted direct field observations using observation sheets, a staple in qualitative research for gathering firsthand data and capturing the nuances of real-world interactions [31]. Additionally, structured interviews with key informants were carried out using interview sheets to collect in-depth insights, enhancing the reliability and validity of the data [32]. Validation of these instruments assessed content appropriateness, construction suitability, and language components, which are crucial for confirming the effectiveness of the tools in capturing the intended measurements. Furthermore, practicality sheets for various educational settings were validated to ensure the usability of teacher and student response questionnaires, assessment questions, and AR-CBL media learning.

The research proceeded with a comprehensive analysis phase involving literature reviews, surveys, and expert interviews to define the requirements for AR-CBL media, employing qualitative methodologies that support triangulating data sources to bolster the robustness of findings Pujiastuti and Haryadi [21]. Observations and interviews with lecturers identified challenges in existing learning processes, which are essential for the context and development needs of AR-CBL media [26]. The development phase included synchronizing media with textbooks and lesson plans, crafting components for CBL-AR media applications, and validating these products. This systematic and iterative approach adheres to established R&D methodologies, ensuring that educational tools meet learning outcomes through validated instruments for assessing student competency achievement outcomes.

3. RESULTS AND DISCUSSION

3.1. Analysis

This study focuses on creating AR instructional media for use in CBL, specifically for computer network subjects. The analysis stage encompasses a preliminary investigation that involves distributing a “needs analysis questionnaire” to students, teachers, and industry professionals. This phase aims to gauge the necessity level of the research by recognizing that all research should address fundamental problems and offer solutions. During the analysis phase, an extensive needs assessment was undertaken to grasp vocational high school students’ unique requirements. A mixed-methods approach was used that blended qualitative and quantitative data collection techniques. Qualitative data were gathered through student discussions, as summarized in Table 1.

Overall, the qualitative data from the discussions and interviews shed light on students’ views regarding the essential competencies they need. Their insights contribute to a deeper understanding of their challenges and align with the broader educational goal of fostering 4C skills for holistic development and future success. The surveys aimed to assess students’ self-perceptions of their 4C skills and educators’ perceptions of students’ abilities in these aspects. Fifty students completed the study, and a questionnaire was used to determine their perceptions of their abilities in the 4C competencies.

Table 1. Identification of learning needs

Competency	Needs identifying	Analysis and insight
Communication	Communication skills to convey ideas.	Communication skills are essential for effective collaboration and conveying ideas.
Collaboration	Cooperative ability to collaborate effectively on group tasks.	Collaboration, a crucial 21st-century skill, involves students understanding the importance of working with diverse groups.
Critical thinking	More vital critical thinking skills to analyze complex problems.	Critical thinking enhances problem-solving and decision-making, highlighting its importance in tackling real-world challenges.
Creativity	Development of creativity skills in formulating innovative solutions.	Creativity, a critical 4C skill, involves understanding how innovation can solve complex problems and create new opportunities.

The survey results in Table 2 show that most students feel less confident in their abilities in the 4C competencies. The average score for critical thinking was 2.8 on a 5-point scale; communication scored an average of 3.0; collaboration scored an average of 2.9; and creativity scored an average of 2.7. For the teacher survey, we used a questionnaire designed to assess their perceptions of students' abilities in these aspects. The survey was completed by 15 teachers who teach in vocational schools. Based on the survey results, critical and collaborative thinking are the areas that require the most attention. Interestingly, a study by Ibanez and Delgado-Kloos [25] found that technologies such as AR can facilitate problem- and project-based learning that can help develop critical and collaborative thinking skills.

Table 2. Results of student and teacher perceptions of 4C competencies

Respondent	Critical thinking	Communication	Collaboration	Creativity
Teacher	2.8	3.0	2.9	2.7
Student	2.6	3.1	2.7	3.0

3.2. Design and development of AR-CBL media learning

AR-CBL is developed using Assemblr Edu. This web-based platform allows educators to create interactive, collaborative, and fun learning activities using 3D and AR elements. Assemblr Edu is an AR platform that allows users to create, share, and experience AR content. When developing AR learning media for computer network learning using Assemblr Edu. AR-CBL media enhancement was carried out at the design stage, which will present prototype 2. The process of completing the AR-CBL media project used Assemblr Studio, as shown in Figure 2. The developed multimedia has four main menus: achievements, guides, materials, and quizzes. The AR camera serves to display the desired 3D image.

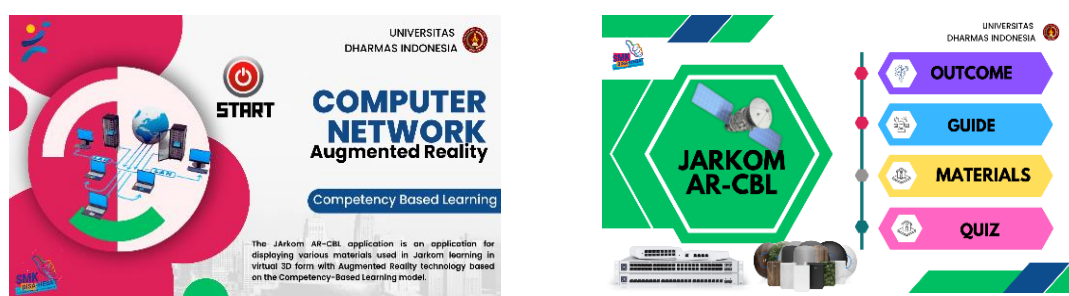


Figure 2. Splash screen and main menu

Recent research [19], [33] in the development of AR technology in learning contexts shows that AR has great potential to improve the teaching and learning process. Several studies have highlighted that using AR, such as 3D objects and videos in an AR environment, allows students to explore lesson concepts from different viewpoints and at their own learning pace [20]. However, successfully applying AR technology in learning requires careful planning and design. Therefore, achieving success at this AR application design stage is a positive indicator of the system's ability to support the development of 4C skills.

Calculating the validity percentage involves several steps. First, the total data collection score (f) must be divided by the maximum score (N). Then, the quotient is multiplied by 100% to get the percentage value. Validation categories are used to evaluate an achievement score's validity level. There are four validation categories used in this assessment. Figure 3 presents the media validation assessment by experts on various indicators, including material, learning design, media design, video design, usefulness, and usage guidelines.

Five experts have assessed each indicator. Overall, the table reflects that the experts positively evaluated the media, although there is still room for improvement. Responses from material and media validators have been taken to ensure that this media development is effective and can be used in various conditions, both in face-to-face settings in class and in online learning. Responses from 45 students to the use of AR-CBL media in computer network learning material showed positive results, as shown in Table 3.

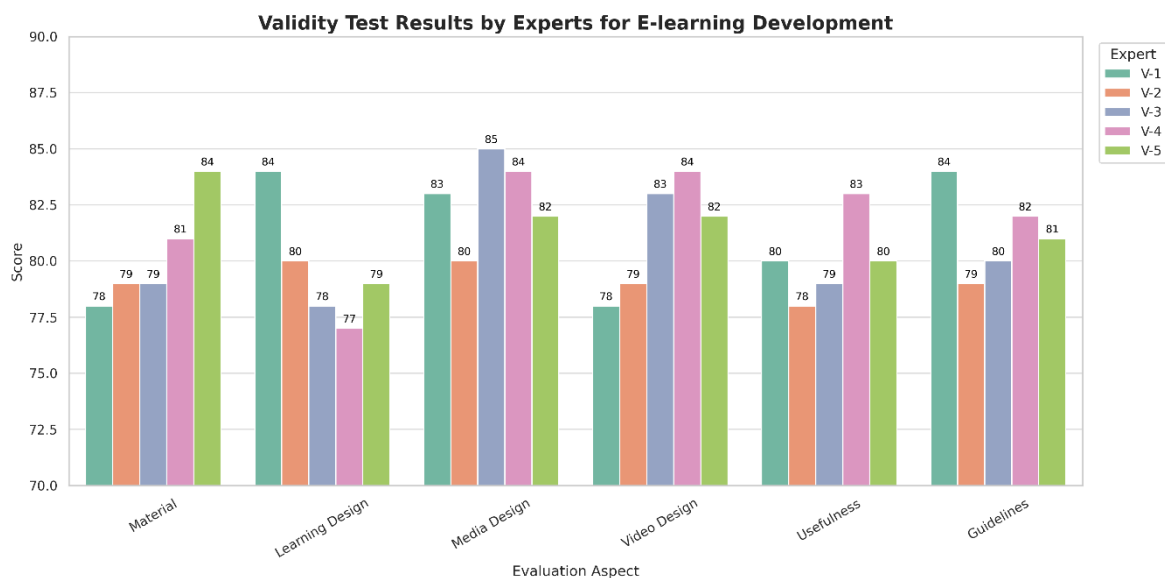


Figure 3. Validity test results by experts

Table 3. Student responses

			Frequency				
No	Aspect	Indicator	NG	PG	G	VG	VVG
1	Media display	Color, shape, and size	29	14	2	0	0
		Images and videos	28	11	5	1	0
2	Media operations	Ease of media operation	32	9	2	1	1
3	Benefits of the media	Makes learning easier	35	9	1	0	0
4	Enthusiastic about using media	It makes it easier to understand the material	32	8	2	2	1
		Exciting and enjoyable learning using 3D AR-CBL	33	8	2	1	1
		Motivate students to study	35	8	2	0	0
		Total	224	67	8	5	3
Percentage: P=(ΣR)/N×100%			71.11	21.27	5.08	1.59	0.95

Note: NG=not good, PG=pretty good, G=good, VG=very good, and VVG=very very good

Most students also consider media operations to be easy. Ease of operation is essential to instructional design because it can influence student engagement and understanding of the subject matter. Almost all students also recognize the benefits of media in facilitating the learning process. This shows that the implementation of AR-CBL technology has been successful in helping students understand the concepts taught in computer networking learning. Enthusiasm for using media is also high. Most students feel that this technology makes it easier to understand the material, makes the learning process more exciting and enjoyable, and motivates them to learn. The survey results show that students responded positively to AR-CBL technology in learning computer networks. Thus, this research supports further use of this technology as a learning aid.

3.3. Implementation and evaluation of AR-CBL media learning

After the design and development stage is complete, the next stage is to test it on the users themselves. The questionnaire results were then tested for validity and reliability with SPSS. The test results state that from 25 indicator items, the reliability test will show the stability and consistency of an instrument, concept, or variable. The Cronbach alpha value obtained from this study can be seen in Table 4. When viewed, all measurement variables used have a Cronbach alpha value of 0.78, so it can be concluded that they have met the internal reliability criteria.

Table 4. Results of descriptive statistics measurement

Measurements	Items	CA	Mean	SD
Ease of use	8	0.823	4.254	0.7756
Functionality and effectiveness	6	0.725	4.264	0.6354
Satisfaction	6	0.764	4.455	0.8122
Outcome/future use	5	0.782	3.922	0.7855

From the interpretation of Table 4, it can be seen that the ease-of-use variable gets a mean value of 4.254, which is included in the neutral category from the user's perspective. In the production process of a new application, it is very natural that in the early stages of the application prototype, many things could be improved in this aspect, especially in the ease of use of the application UI. In addition, other things users need sometimes cannot be accommodated quickly because, in AR, the developer controls all of its [22], [34]. There are indications that users using this AR-CBL application for the first time need to adapt to the existing navigation system until they get used to using this application to view computer network learning materials.

In the function and effectiveness variables, it is more likely to assess how the user experience (UX) the clarity of information provided in this application (user experience-UX). In mobile applications such as this AR application, UX requires special attention because information to users is limited by these media devices [13], [24]. This variable generally gets a higher mean value than the previous variable. This means that users get clear information from various aspects of the media included in this application, such as aspects of sound, images, text, video, and 3D models. The results of the satisfaction variable above are reinforced by the results of the last variable, namely the outcome, with a mean of 4.455. This proves that AR-CBL can help the interaction between teachers and teachers to continue creating learning innovations.

The findings show a positive response from users towards the AR-CBL application in computer network learning. Several previous studies [35], [36] have investigated the acceptability and effectiveness of AR technology in educational contexts. However, our findings deepen the understanding of user responses to AR-CBL applications, especially in computer network learning. Several researchers, such as Zapata *et al.* [33] highlight challenges in accepting AR technology, such as the complexity of use, device limitations, and sufficient training to use it effectively. However, this research shows that although there are challenges in the initial stages of adaptation, users experience satisfaction and are interested in continuing to use this AR-CBL application in their daily learning activities. In addition, previous research also highlights the importance of focusing on UX in AR application development. Our findings align with this, where user responses to the clarity of information provided in the AR-CBL application indicate a positive experience.

3.3.1. Effectiveness in the cognitive aspect

The effectiveness test in the cognitive domain is seen based on the results of the student knowledge test through learning outcomes. This effectiveness test measures the extent of student learning and understanding of computer network subjects with AR-CBL model. In this test, a written test was conducted on 46 students, divided into two classes: a control class with 24 students and an experimental class with 22 students. The control class is a class that does not experience any treatment or what has been taught by students. The experimental class is a class that gets treatment by implementing the AR-CBL that has been developed. To find out descriptive statistical data regarding the effectiveness of test results, the results of which are shown in Table 5.

Table 5. SPSS test table for experimental and control groups

Statistics		
Descriptive statistics	Control group	Experiment group
N	Valid 24	22
	Missing 0	1
Mean	74.4286	86.0500
Median	74.0000	86.0000
Mode	72.00	920.00
Sum	16151.00	14231.00

Multiple modes exist. The smallest value is shown.

The difference becomes more apparent when we look at the graph in Figure 4, where an increase in learning outcomes in the experimental class appears significant. The application of AR-CBL media not only assists in enhancing understanding of lesson materials but also potentially boosts student engagement and motivation during the learning process. This analysis confirms that innovative approaches like AR-CBL media during teaching can positively impact students' learning outcomes. Consequently, these findings support

adopting and integrating educational technologies like AR-CBL into teaching and learning practices to enhance their effectiveness.

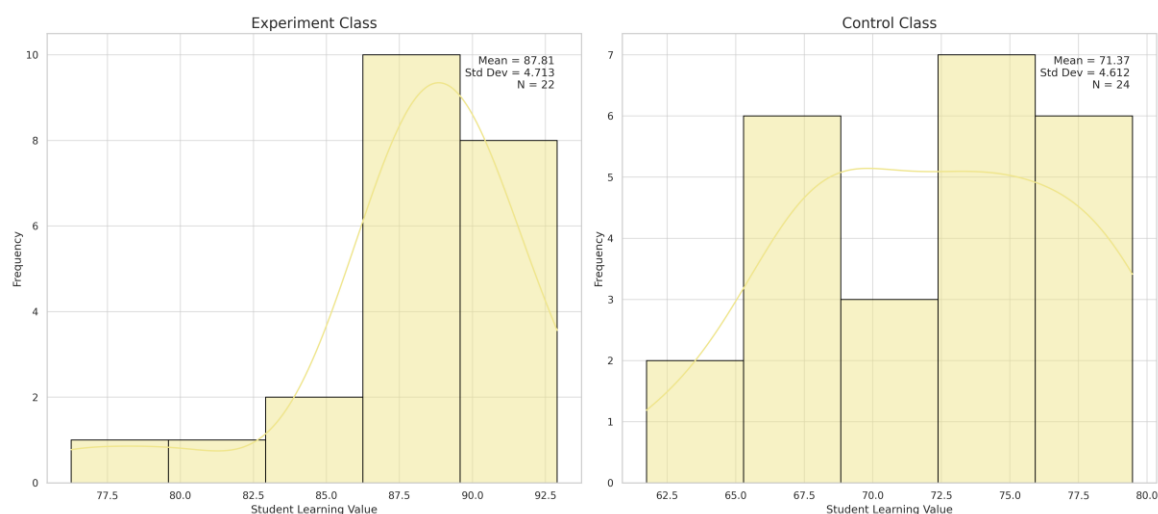


Figure 4. Histogram graph of control class and experimental class

An in-depth analysis of this research shows that using AR-CBL media in learning can significantly contribute to increasing students' understanding and academic results. These findings are consistent with research results presented [35], [37], which show that AR technology, such as AR, can potentially increase interactivity, engagement, and learning effectiveness. One crucial aspect that needs to be considered is the significant difference between the experimental group that used AR-CBL and the control group that used conventional learning methods [36]. Shows that implementing AR-CBL can provide real benefits in increasing student learning achievement. The results of this study provide strong support for using AR-CBL technology in learning contexts. By utilizing this technology, educators can create a more dynamic, exciting, and effective learning environment for students.

3.3.2. Effectiveness in the affective aspect (4C competencies)

The effectiveness of affective aspects in the learning context can be measured through observations made by researchers during the learning process. The affective assessment instrument measures affective elements in a larger group of students, in this case, the experimental class. This class emphasizes the development of four key competencies (4Cs): creativity, critical thinking, communication, and collaboration all essential elements in meeting the needs of the 21st-century. A practical assessment instrument may be a Likert scale-based observation rubric used during instruction to evaluate the 4Cs of students in the class experiments taking computer network subjects.

The data presented in Table 6 shows a significant increase in students' 4C competencies during the learning process using the CBL model supported by AR. This increase was seen in all competencies, but the most significant was in creativity and collaboration. This may indicate that AR facilitates active and interactive learning, encouraging students to think creatively and collaborate.

Table 6. The results of observations 4C competency

Critical thinking		Creative		Communication		Collaboration	
A-1 mean	66.45	A-1 mean	72	A-1 mean	71	A-1 mean	70
A-2 mean	73.55	A-2 mean	78.15	A-2 mean	79	A-2 mean	80
A-3 mean	77.85	A-3 mean	85.85	A-3 mean	83	A-3 mean	85
A-4 mean	79.35	A-4 mean	84.65	A-4 mean	84	A-1 mean	82
Average	74.3	Average	80.16	Average	79.25	Average	79.25

This research reveals the potential of AR-CBL technology as an effective supporting tool in the context of computer network learning at the vocational education level. Previous research [36], [23] has

highlighted various ways new technology can improve the quality of graduates. One approach that has been identified is integrating technology in learning to enhance understanding of the material, facilitate collaboration between students, and increase engagement in the learning process. Using AR-CBL, educators can create a more dynamic learning environment and allow students to apply their knowledge directly in relevant contexts. Thus, this research not only underlines the potential of AR-CBL as an innovative learning tool but also strengthens previous findings that highlight the role of technology in improving the quality of graduates, especially in the context of vocational education. By utilizing this technology effectively, educational institutions can prepare students with skills relevant to the needs of modern industry and the job market.

Combining fun learning with AR technology has significantly increased students' interest and skills in studying computer networks. These results are in line with previous research findings [11], [36] showing the effectiveness of AR in enhancing the learning experience. The proposed AR-CBL media, designed with a human-centered design approach, has proven helpful in treating severe interactions and relevant content for educational purposes. Thus, it can be concluded that combining AR with computer networking learning increases students' interest, strengthens their understanding, enriches the learning experience, and offers excellent potential for skill enhancement in this field.

AR-CBL media has been evaluated on vocational school students; course interface design is applied to measure learning effectiveness and user participation in learning methods. The trial results data were very positive; the game facilitates students' CBL. Doing exercises and projects related to learning computer networks in a fun learning atmosphere. The innovative aspect of this research lies in applying AR in the context of CBL. The emphasis on human-centered design when developing this application also provides a new approach to ensure that the application is practical in conveying serious learning material while remaining attractive to students. Finally, using games as part of the learning process is another innovative aspect that can increase student participation and motivation.

4. CONCLUSION

AR has become an increasingly popular interactive method for enriching learning experiences. This technology allows users to experience the virtual world in their natural environment, effectively increasing user engagement with the application and creating the illusion of digital objects around them. This research discusses implementing AR technology based on CBL as a tool in the computer network learning process, changing the usually monotonous learning process into something exciting and fun for vocational school students. This technology allows students to learn practically and interactively while developing communication, collaboration, critical thinking, and creativity skills. The integration of AR in computer network learning has opened a new path for a learning approach that is more contextual and oriented towards practical applications, in line with modern trends in vocational education.

AR media based on CBL has been evaluated by vocational school students as part of their computer networking curriculum. Assessment design is used to assess the effectiveness of learning methods and the level of student participation. The trial results showed positive data; AR-CBL media has made learning more enjoyable for students and increased their understanding of the subject matter. In addition, the experimental and control groups saw increased learning outcomes-an indicator that computer network material can be understood through AR-CBL media simulations. Although most respondents provided positive feedback about learning activities using AR-CBL media and did not face significant difficulties when using the technology, some negative or neutral responses regarding the level of difficulty or boredom when using this media need to be followed up in the future.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

CONFLICT OF INTEREST STATEMENT

No conflict of interest

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

When papers talk about using people or animals, authors should make it clear that the research followed all national rules and institutional policies, and it was approved by the authors' institutional review board or a similar committee. The Helsinki Declaration's tenets must guide all investigations involving human subjects. Authors must also identify the committee or review board approving the experiments and provide a statement indicating approval of the research. Incorporate the following (or a similar) statement: The research related to human use has been complied with all the relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration and has been approved by the authors' institutional review board or equivalent committee; or: The research related to animal use has been complied with all the relevant national regulations and institutional policies for the care and use of animals.

DATA AVAILABILITY

The data supporting the findings of this study are available within the article [and/or its supplementary materials].

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